Arctic 2012 LVIS-LARC ICEBridge Land Ice Flight Lines

Prepared: Feb 15th 2012

The following document presents LVIS flight lines to be considered for the Spring 2012 Greenland OIB deployment. The constraints and guidelines used to develop the flight lines are outlined.

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Direct connection to OIB Baseline Science Requirements:

IS1: Measure surface elevation with a vertical accuracy of 0.5m or better.

IS2: Measure annual changes in ice sheet surface elevation sufficiently accurate to detect 0.15m changes in uncrevassed and 1.0m changes in crevassed regions along sampled profiles over distances of 500m. We are repeating existing altimetry lines flown by ATM and LVIS 2009-2011. Where the existing altimetry data were laid down by ATM, the sampled profiles will be at the width of the ATM swath (400m) and where the data were laid down by LVIS will be in excess of 1.2km.

IS7: Collect elevation data so that the combined ICESAT-1-OIB sampling provides an elevation measurement within 10km for 90% of the area within 100km of the edge of the GIS. Each area has a densification of flight lines within 100-km of the edge of the continuous GIS.

IS8: Approximate flow line mapping of selected glaciers is implemented.

IS6: Remeasure surface elevation along established airborne altimeter and ICESat lines that extend from near the glacier margin to near the ice divide. Several candidate ICESat- 1 tracks selected based on their temporal and along-track sampling between the glacier margin and divide. In addition, the LVIS swath mapping provides an abundance of ICESat-1 and future mission (ICESat-2) underflight data that samples near the glacier margin to near the ice divide.

IS9: Measure once surface elevation across flow transects at 3km and 8km upstream of the terminus. Flight lines provide the opportunity to acquire the across flow transects.

IS11: Measure elevation over 10 Greenland glaciers that are rapidly changing. Each area has a densification of flight lines to provide the basis of 5-km grid sampling with better than 10-km sampling for the surrounding regions of glacier lower catchments.

The flight lines also provide excellent sampling of GRACE "global-ice" mascons (see Figure 11).

Information used when placing lines:

1. Existing Icebridge altimetry lines from 2009, 2010 and 2011 (Coordinates from John Sonntag, Feb 2012).
2. Icesat lines where good temporal and spatial coverage exists (in NW Greenland) or are shared with the P3 plan (in Jakobshavn area)
3. Icesat lines where poor temporal coverage exists (S Greenland)
4. Icesat lines where good spatial and temporal coverage exists and that cross the main mapping lines in NW and SE Greenland (for crossover analyses).

5. Glacier centerline targets (in SW Greenland) – see section below for supporting information
6. Lines extending from the ice sheet terminus to the divide – several ICESat lines (with good temporal and spatial coverage) identified in NW Greenland (to be used for transits or as crossing lines where it makes sense). Line 0166 in S Greenland also a good candidate (overlap with #3 above).
7. Flow lines up to and over divide in S Greenland (to be used for transits where it makes sense). Flow line map provided by Bea Csatho, based on Thomas et al., Science (2000).
8. Actual ICESat footprint data (not reference tracks) used to specify ICESat line locations.
9. Opportunity to overlap P3 2012 lines (engineering data for continued ATM/LVIS intercomparisons) (e.g., Icesat track 0300)

There are 100 science flight hours approved with ~15 possible flight days possible. At the time this was written, the Falcon Jet duration and speed parameters are not finalized, thus making it premature to develop specific flight plans. However, we expect a clearer picture of plane readiness in the next couple of weeks. Flight plans will be developed each to gather scientific data that meet the Level 1 requirements and guided by the priorities defined by the Science Team.

Line Priorities to be used when planning flights, in order:
(refer to figures 1-5 for color coding)

1. SW glacier lines (from Kanger base) (green lines, red boxes)
2. Icesat lines in NW, Jakobshavn (P3 lines), and S Greenland (purple)
3. 2010 Repeat Altimetry Lines in the NW (dark brown and red). Start with 10km spacing, densify to 5km with subsequent flights. *
4. New 2012 lines in W and NW (light blue). *
5. 2011 Repeat Altimetry lines in the NW and W (light brown)*
   *Icesat tracks from terminus to divide (black dashed) or other Icesat tracks (purple or dashed purple) used as crossing lines
6. 2010 Repeat Altimetry lines in SE (dark brown and red)**
7. New 2012 lines south of ~62S (blue)**
8. 2011 Repeat Altimetry lines and new 2012 lines in SE (light brown and blue)**
   **Icesat tracks (purple) or flow lines (orange) to be used as crossing lines
9. Canadian icecap lines (Figure 10)

Information still needed:

1. Sea ice flight lines (3 primary, 2-3 in reserve)
2. OK to priorities
3. SW Glacier lines: prioritize glaciers for complete vs centerline mapping. Lines still need adjusting once plane capabilities established.

Figure 1: Greenland 2012 LVIS-LARC OIB lines colored by type.

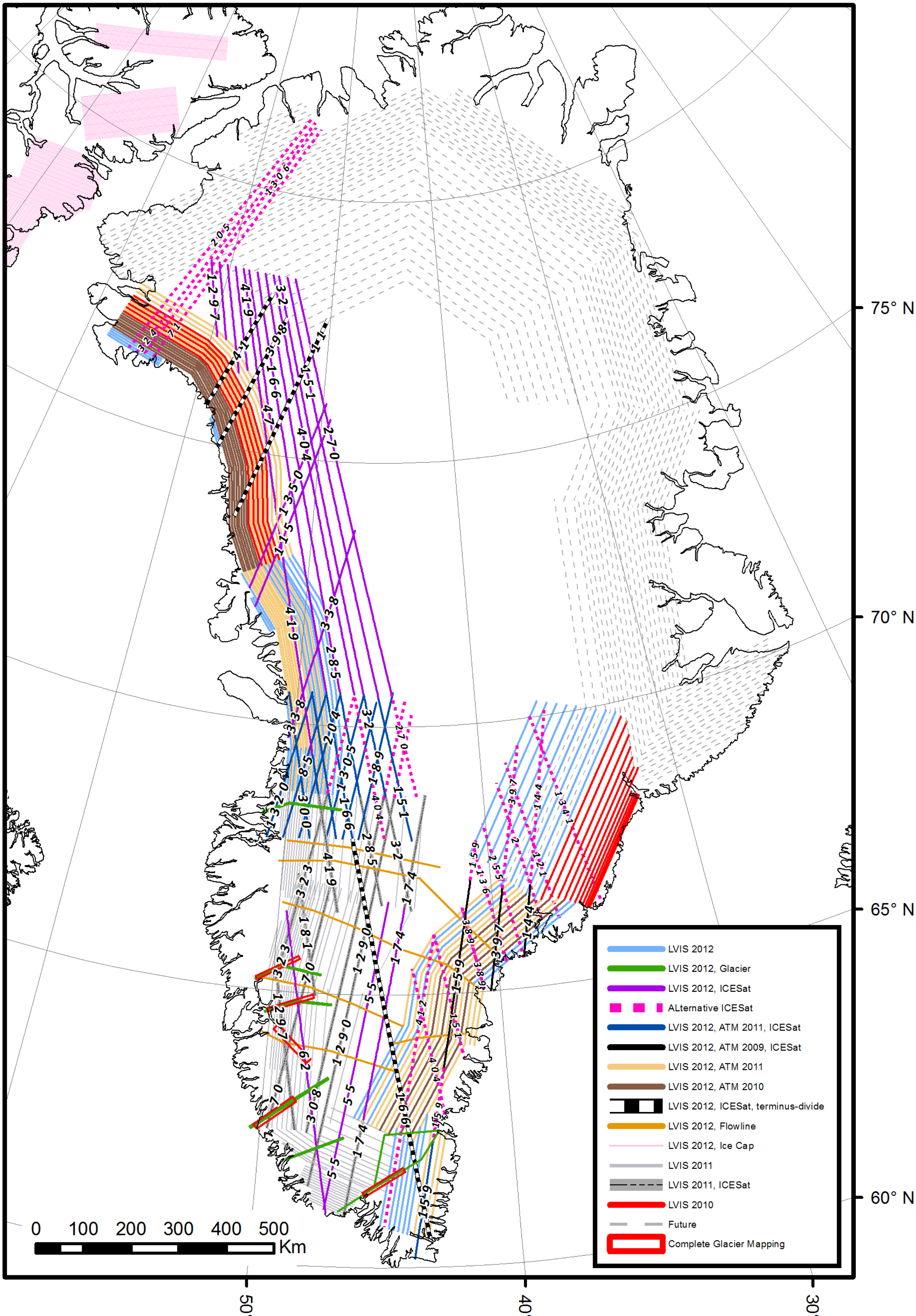


Figure 2: Close up of Greenland 2012 LVIS/OIB lines in vicinity of Thule.

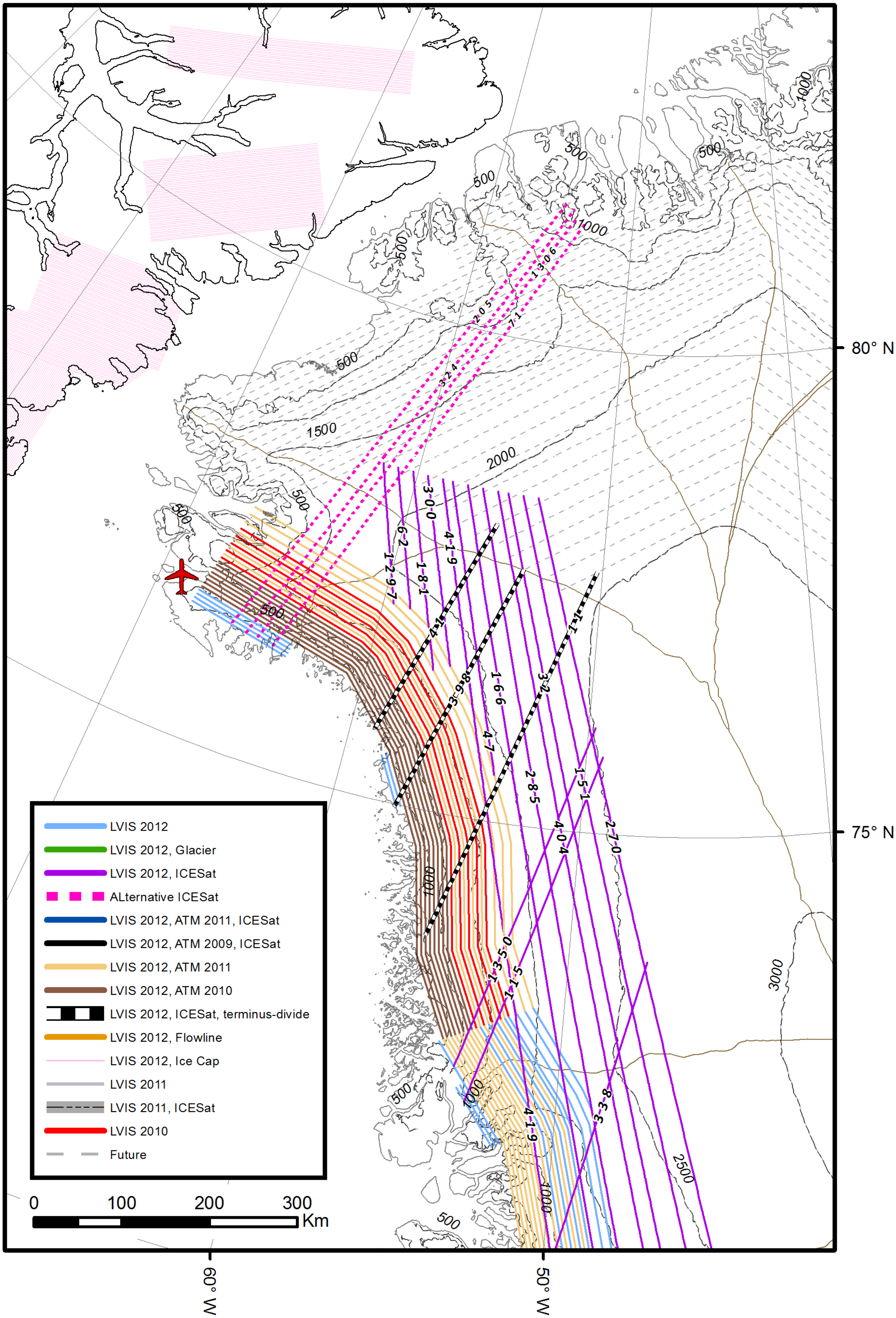


Figure 3: Close up of Greenland 2012 LVIS/OIB lines in vicinity of Kangerlussuaq.

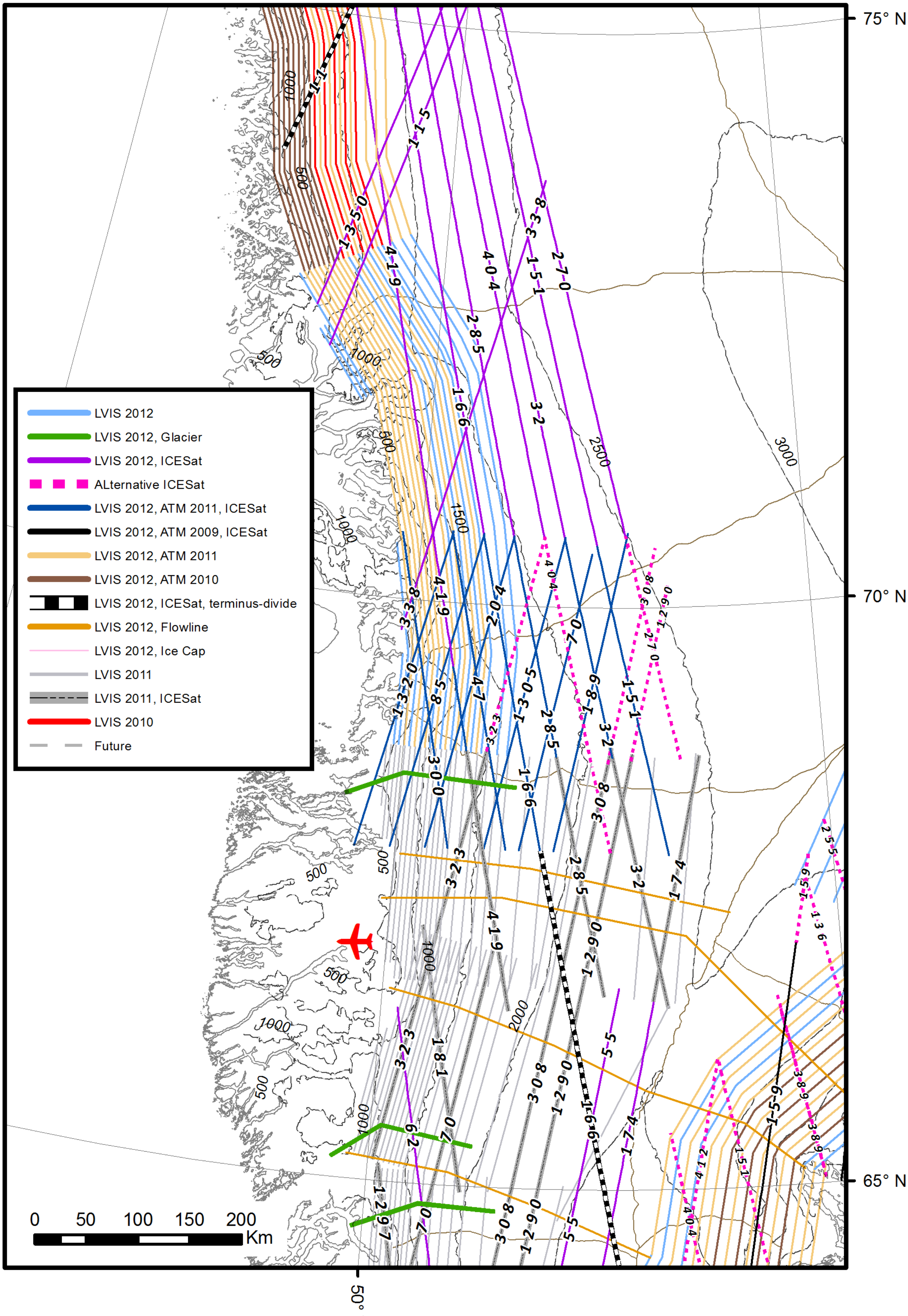


Figure 4: Close up of Greenland 2012 LVIS/OIB lines south of Kangerlussuaq.

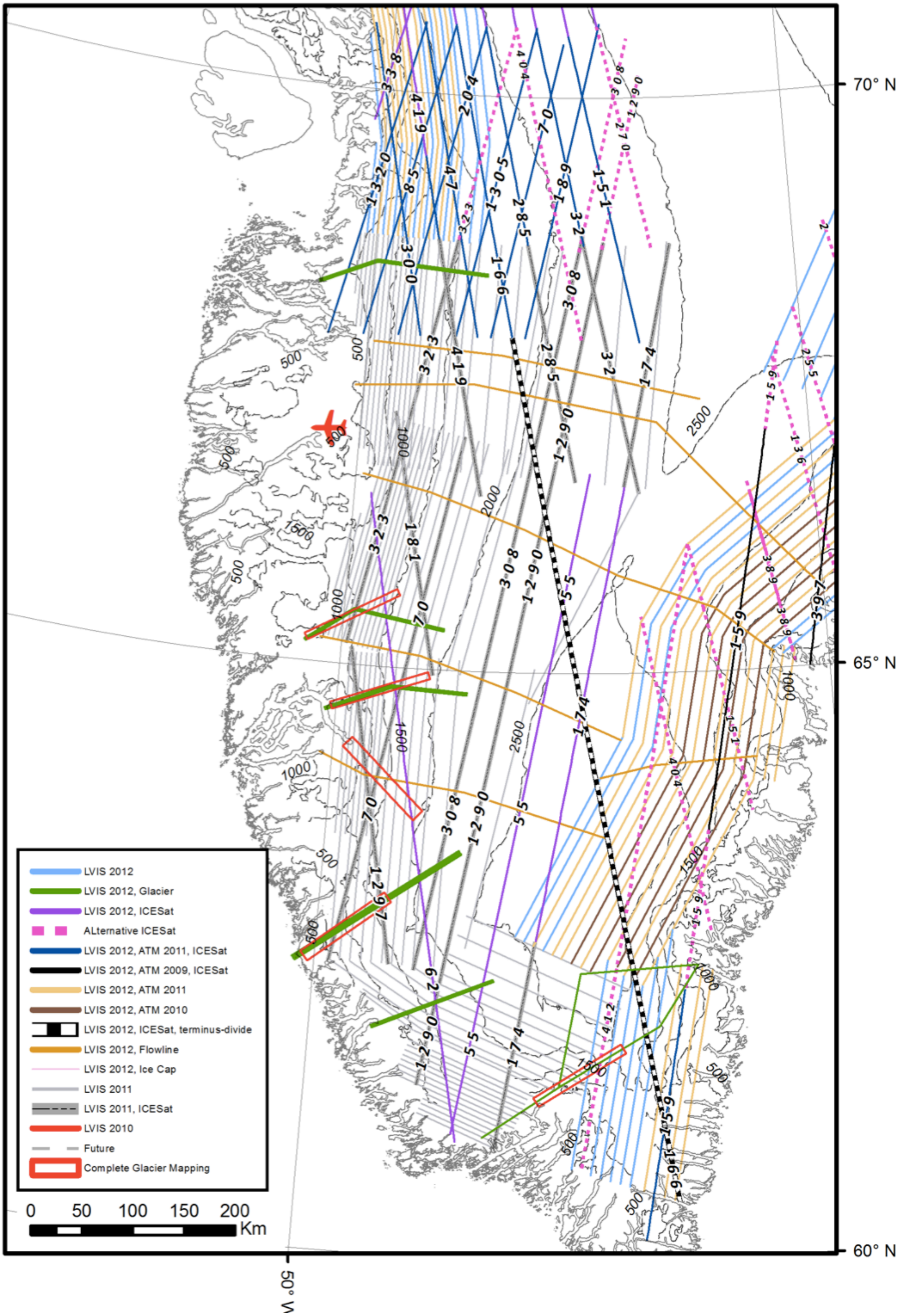
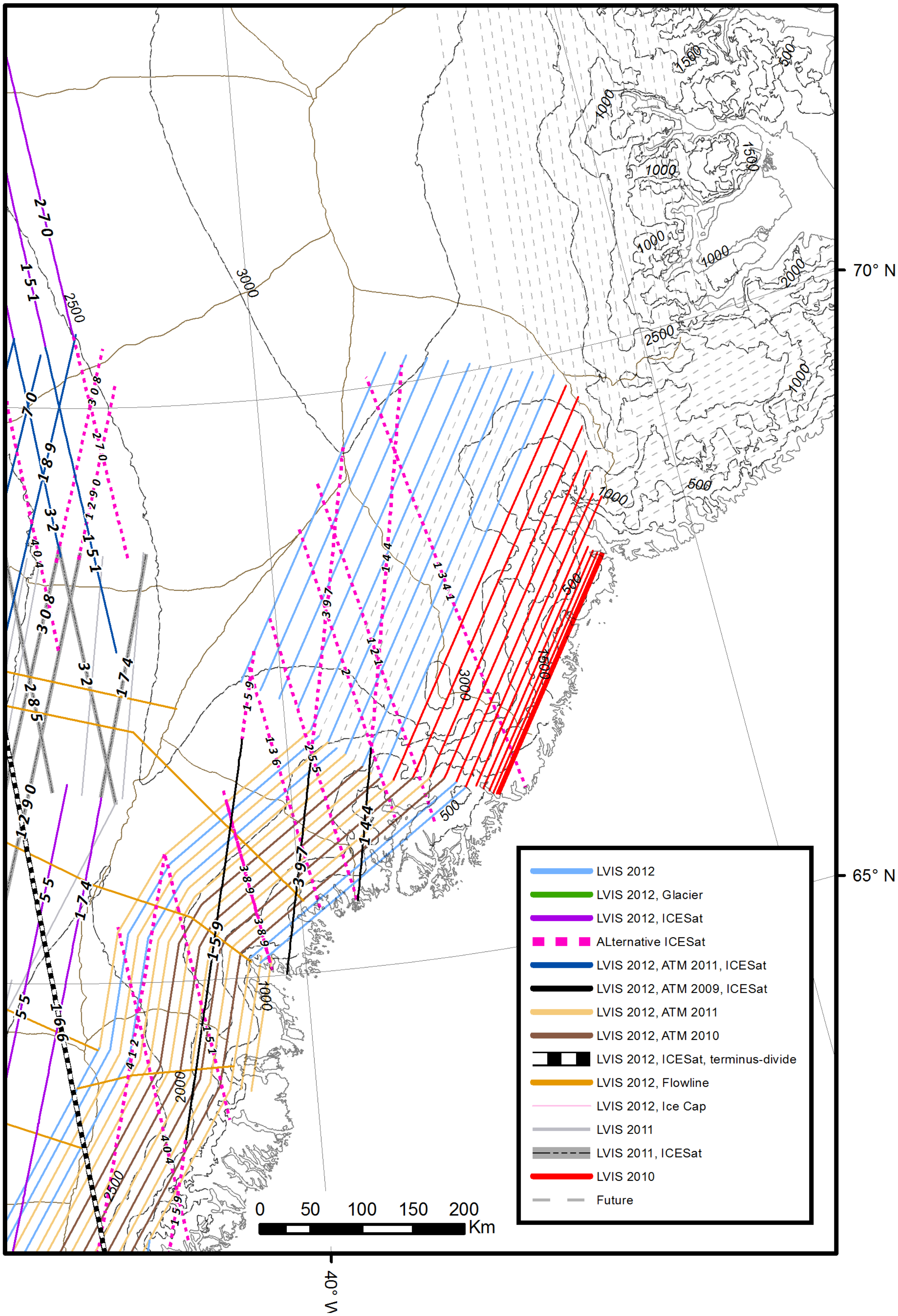


Figure 5 Close up of Greenland 2012 LVIS/OIB lines east of Kangerlussuaq.



SW Glacier lines:

ID	Glacier name	Long	Lat	RP	FP	Behavior 50s	80s	2000s	Note	Box flight	Reference
1	Nordenskjold	-50.62	68.39	M	H	R	A	Fast and slow thinning alternating	Xover 5011037, complex spatial and temporal behavior	B5F6	Weidick 1991
2	Unnamed	-48.86	62.24	M	L	R	R	recent strong thinning		B5F6	Weidick 1991
3	Isunnguate Sermia	-50.1	67.2	L	L	R	A	recent strong thinning		B5F6	Weidick 1991
4	Ice sheet near Sukkertoppen	-49.93	65.73	L	L	R	A	complex behavior		B34F6	Weidick 1991
5	Saqqap Sermia	-50.38	65.3	L	H	A	A	stable first, followed by thinning, 2001034		B34F6	Weidick 1991
6	Narsap Sermia	-49.58	64.7	H	H	R	A	increasing thinning, especially since '08;	The only region always thinning and retreating since 1950s -- velocity increased in the 2000s	B34F6	Weidick 1991; Joughin et al 2010, Thomas et al., 2009
7	Kangiata Nunata Sermia, N	-49.5	64.2	H	L	LR	R	thinning, -2 m/yr at 1000 m		B34F6 also B2F4	
8	Kangiata Nunata Sermia, S	-49.5	64.2	H	H	LR	R	-2 m/yr at 1000 m, dynamic thinning from ATM		B34F6	
9	Isortuarsuup Tasia	-49.8	63.82	L	L	?	A			B34F6	Weidick 1991
10	Frederikshab Isblink	-49.8	62.6	H	H	R	R	1.7 m thickening (P)	landterminating, contraversary behavior	B34F6	Weidick 1991
11	Akulleq Brae	-48.86	62.24	L	L	N	A			B2F4	Weidick 1991
12	Unnamed	-48.6	61.96	L	L	N	A			B2F4	Weidick 1991
13	Sermiligaarsuk Brae	-48.11	61.66	L	H	N	A	?		B2F4	Weidick 1991
14	Qajuuttap Sermia	-45.44	61.5	H	H	A	A	Thickening followed by recent thinning,	very well documented, best in Greenland	??	Weidick 2009

RP: Region priority, FP: flight priority, H: High, M: Medium, L: Low, R: retreat, A: advance, N: not known

Table 1: 14 priority glaciers for mapping in the SW, provided by Bea Csatho.

We have included the mapping of several high priority glaciers into the high altitude plans for 2012. After several discussions on how best to map glacier center/flow lines from high altitude, we have worked up two approaches for further discussion by the Science Team:

1. **Centerline** mapping: provides a baseline for a number of different glaciers. It works well for glaciers that are predominantly linear in shape, but requires segmented lines and maybe some misplaced data during the turns if not.

2. **Coverage** mapping: provides a spatially complete baseline map and with LVIS's ~2 km wide swath a 15km by 100km area can be mapped in a single flight (e.g. Kangiata Nunatak Sermia, Figure 7). With repeat mapping it allows analysis of the effect of different sampling (cf Larsen and Arendt papers from Alaska).

Figures 6 to 8 show Bea's top choices for both approaches. They're presented for further discussion by the team as to which approach is the most appropriate for each glacier.

Candidate glaciers for option 1: Centerline mapping

(based on ATM coverage, thinning history, etc,):
1. Nordenskjold, curved glacier, ~ 6 km wide
5. Saqqap sermia, straight glacier, ~5 km wide
6. Narsap sermia, straight glaciers, ~ 4.5 km wide
10. Frederickshab Isbrae, curved glacier, ~ 7 km wide
12. Unnamed glacier near Nunatarsuaq, straight glacier, ~ 4 km wide
14. Qajuuttap Sermia, this is actually three glaciers + a rapidly thinning ice sheet margin, the glaciers are 2-4 km wide

* Probably sufficient to have one flight along the straight glaciers, depending how well you can aim at the centerline. Ideally the wider and curved glaciers should be covered by parallel lines.
* Consider the curves of the flowline and the straightline fit as end members. The important area is the fast flowing part of the glacier.

Candidate glaciers for option 2: Coverage mapping

8. Kangiata Nunatak Sermia, southern branch, this glacier is the most dynamic in SW Greenland and thinning rapidly. I believe that it has been surveyed by ATM repeatedly, but a complete coverage would be great
5. and 6. Narsap and Saqqap, this is an exciting pair of glaciers, one is land terminating and the other is marine glacier and they must have similar climate forcing.
14. Qajuutap sermia; we don't know much about elevation/thickness changes, but this glacier has the most well documented retreat history.

Figure 6. Nordenskjold Glacier lines, oriented to match the centerline and maximum flow line. Coverage at the join may get misplaced.

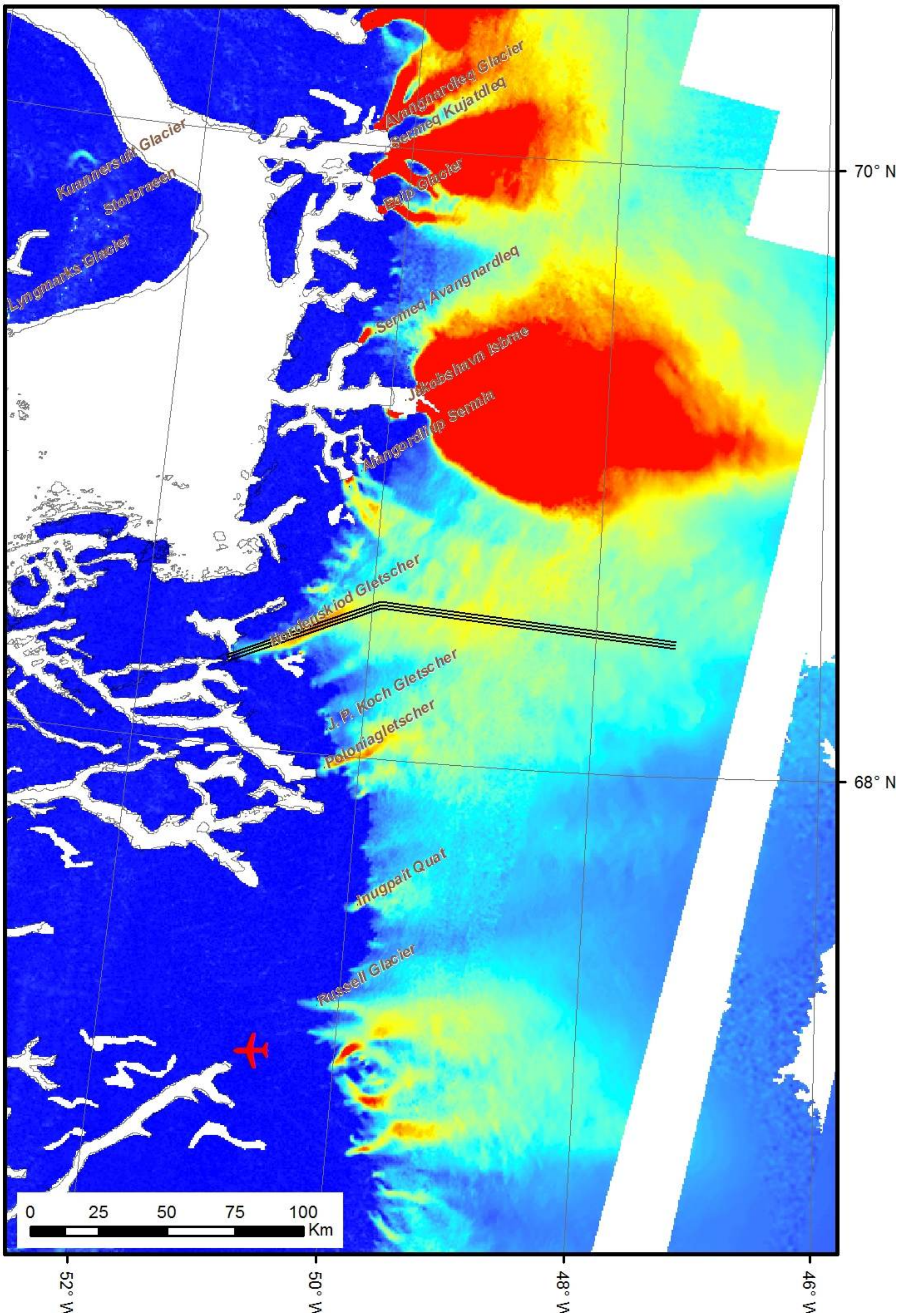


Figure 7. Black lines: Centerline approaches for Saqqap and Narsap Sermias, Frederickshab Isbrae and an Unnamed glacier. Red boxes: Complete mapping approach for Saqqap, Narsap and Kangiata Nunatak Sermias. Saqqap and Narsap Sermias can be mapped in a racetrack approach (each box is 9km by 100km). Kangiata Nunatak Sermia and Frederickshab Isbrae show the 100km by 17km boxes each possible in a single flight.

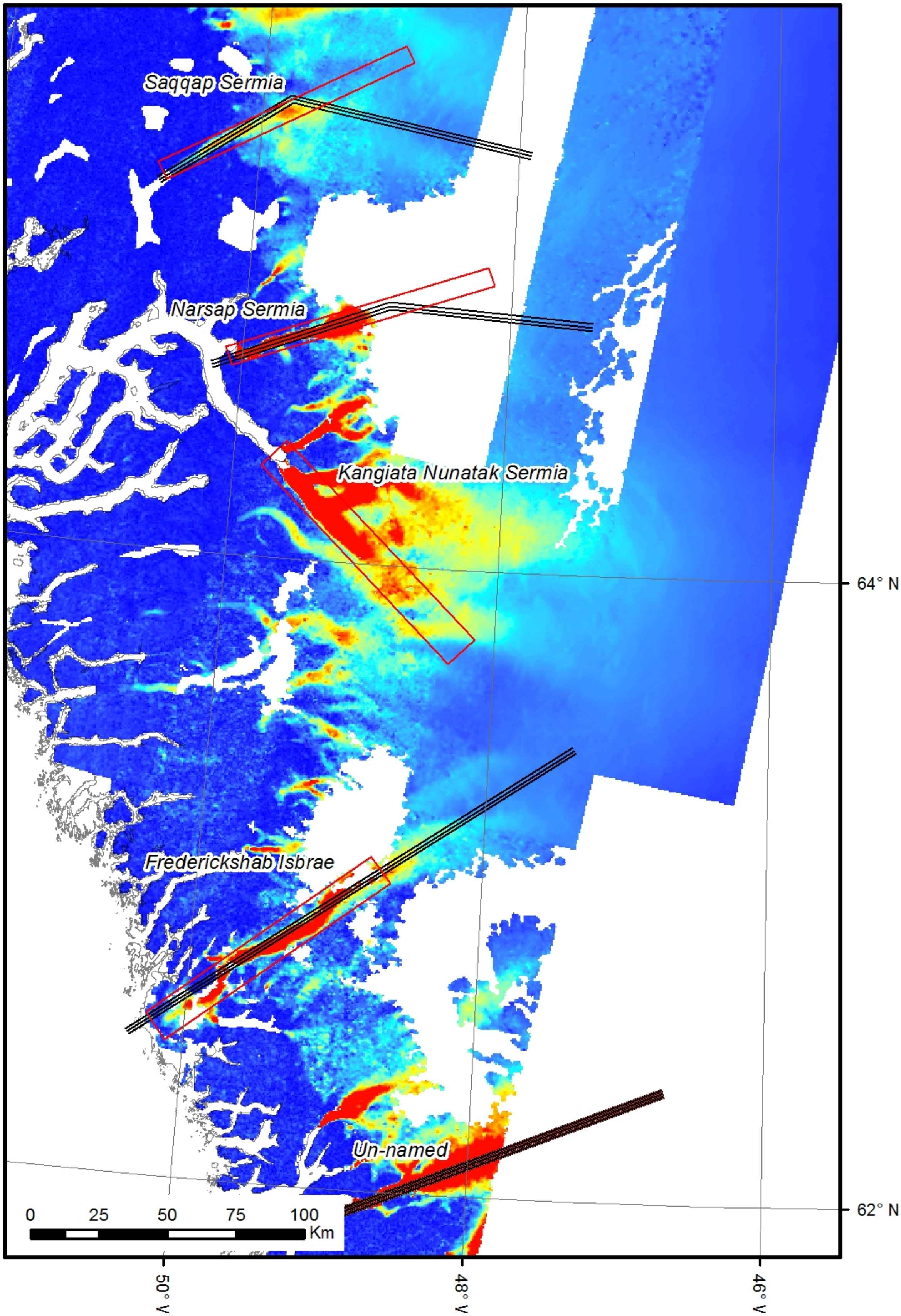


Figure 8. Centerline (black line) and complete mapping approaches (within red box 10x100km) for Qajuutap Sermia.

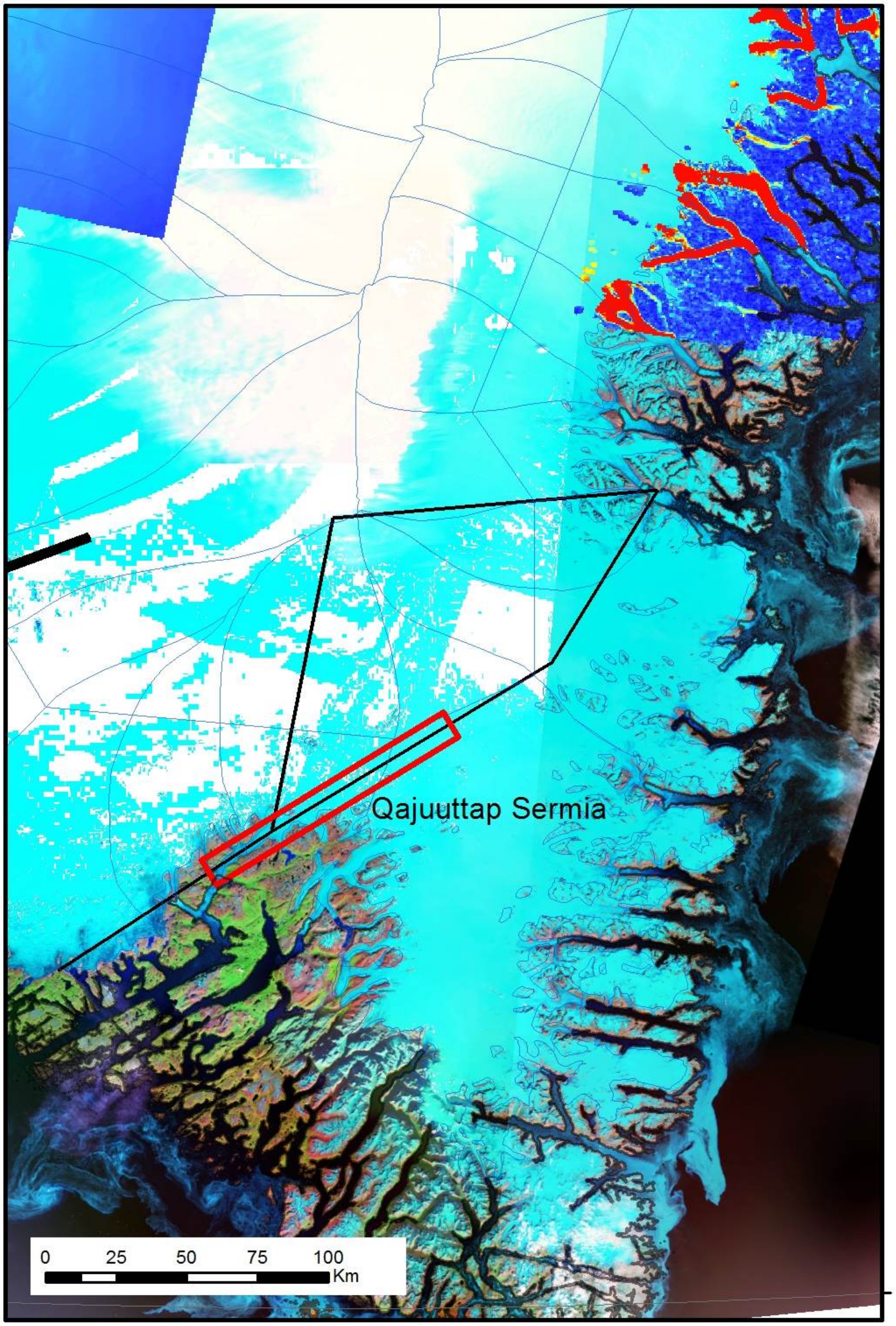


Figure 9: Backup flight locations: Penny and Barnes icecaps, Baffin Island.

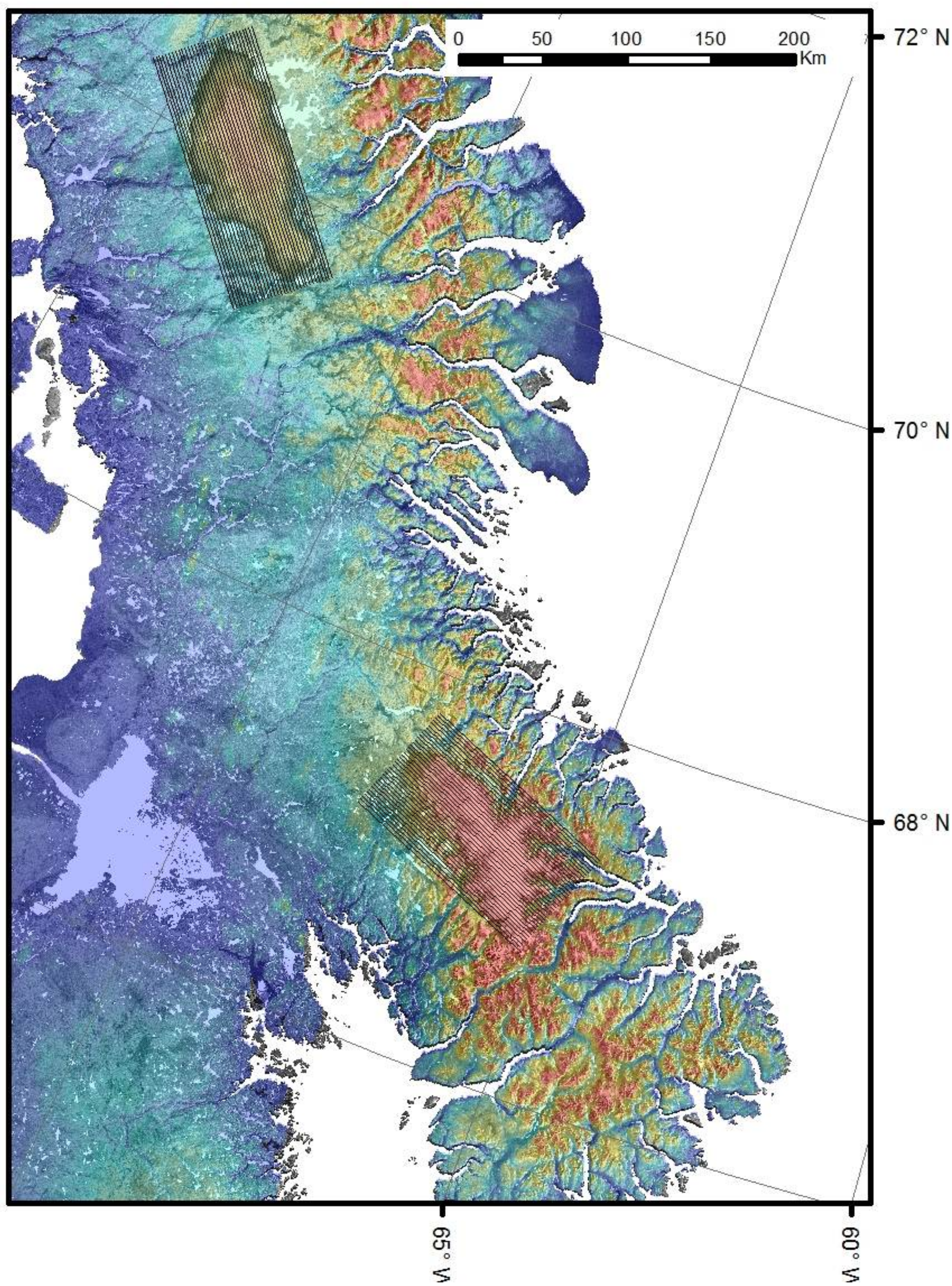


Figure 10. Example flight plan , repeat 2010 ATM lines (10km spacing). Thule base, 5hr duration.

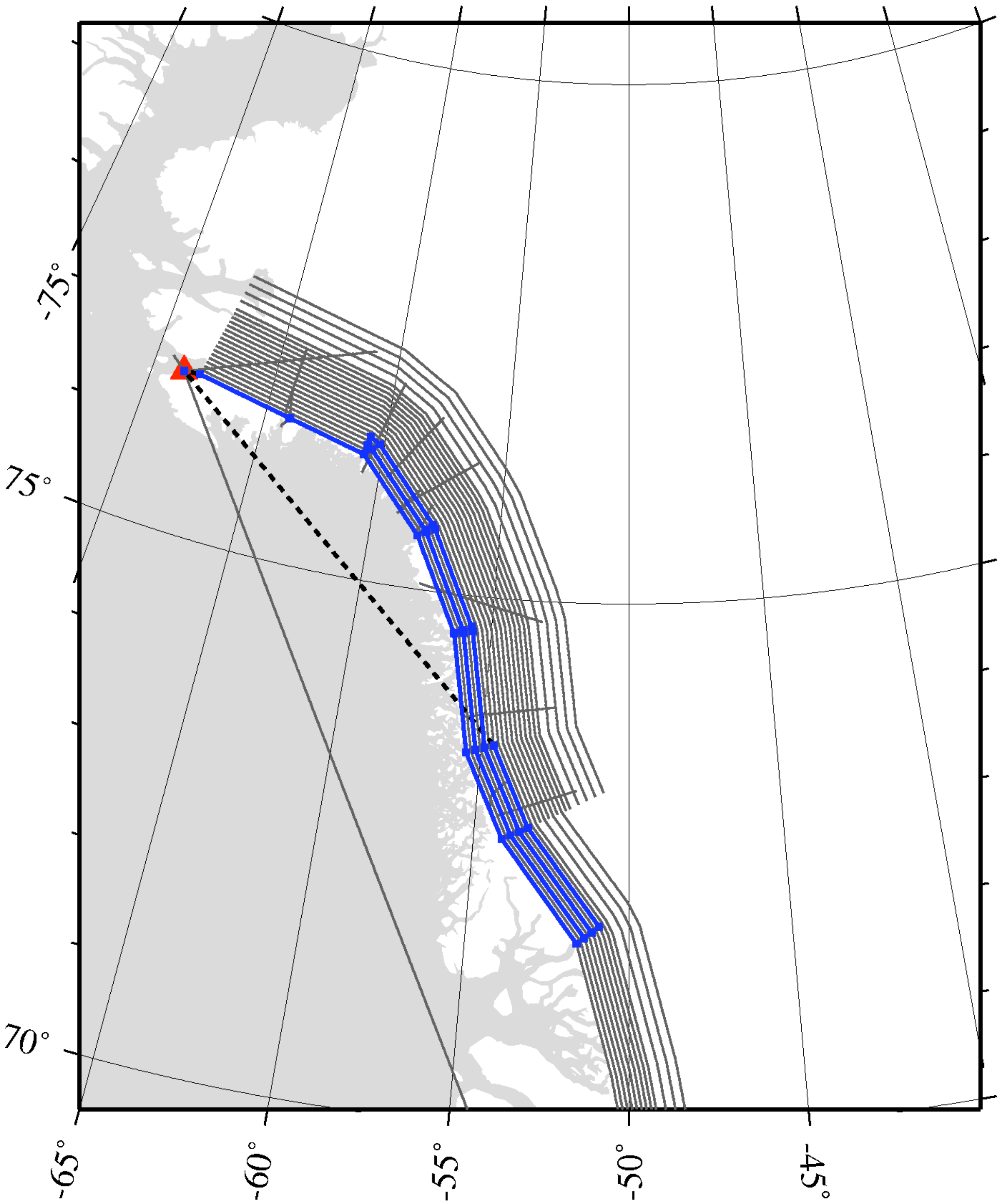
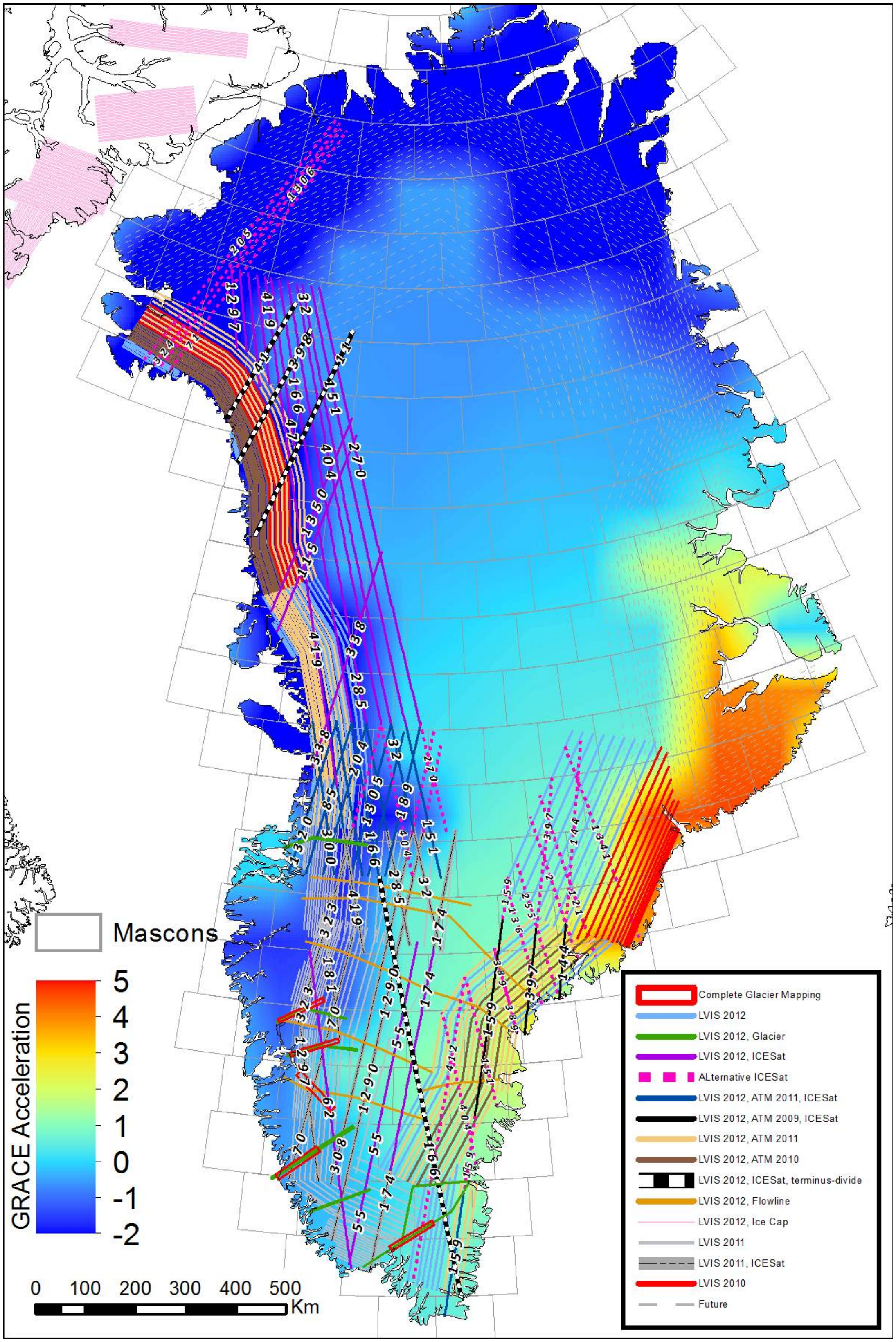


Figure 11. LVIS 2012 OIB Lines on GRACE observed acceleration (provided by Scott Luthcke).



Arctic 2012 LVIS-LARC ICEBridge Sea Ice Flight Lines

Prepared: March 6th

Updated on April 15th 2012.

The following document presents LVIS flight lines over sea ice for the Spring 2012 Greenland OIB deployment.

Document contributors:
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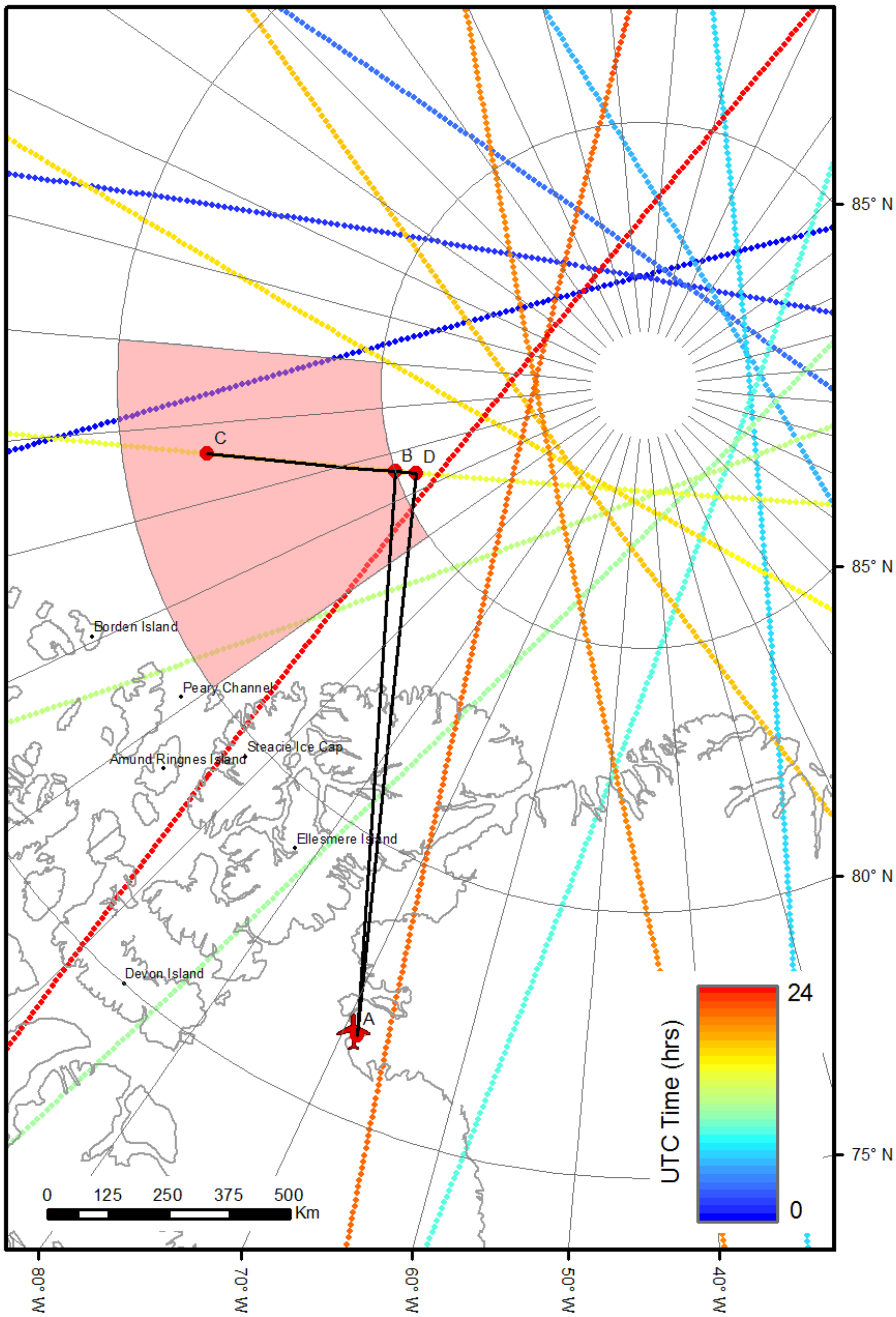
Wingham Box			Priority: Highest
Time to 1st Pt	Plane speed	Total Flight Time	Mission Time
101 minutes	375 knots	270 minutes	272 minutes

This flight will cover the "Wingham Box", a region in the arctic where the Cryosat satellite is operating in SARin mode. The flight is designed to fly a Cryosat orbit that intersects the majority of the box (designated in red in Figure 1). All Cryosat underflights will be fine-tuned closer to the mission as more accurate Cryosat orbits are provided from the science team.

Requirements:

1. Track flown is within 2 hours of Cryosat measurements
2. Track measures as much area in the box as possible
3. Time permitting, flight should extend 50-100km before and after the box
4. It should be noted whether orbit flown is ascending or descending
5. Flying a portion of a track in both directions is preferable to flying a longer section in only one direction.

Figure 1. Example Wingham Box Flight. Track will be selected on day of flight



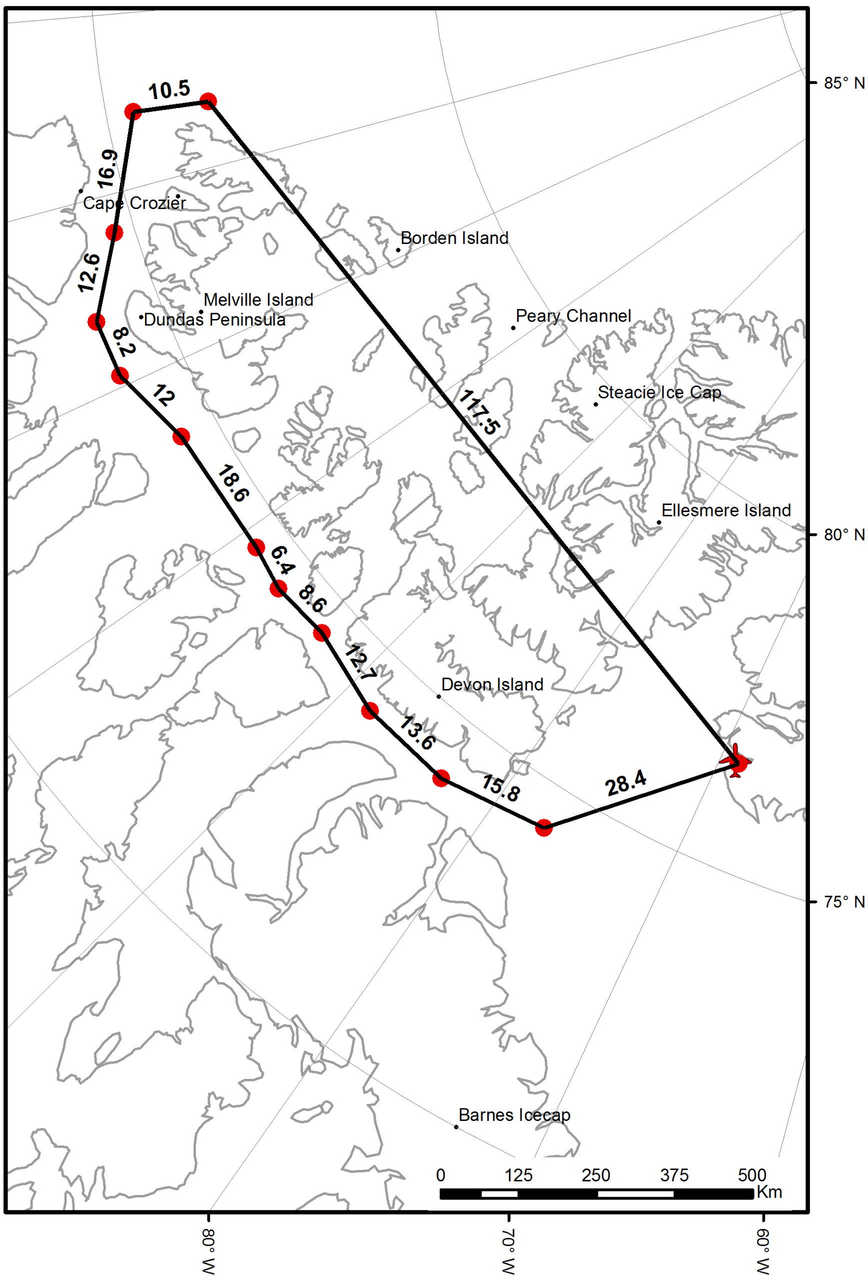
Notes after 3/9/2012 telecon

- Doesn't matter so much where the track located in the box, as long as it goes through the majority of it.

NorthWest Passage			Priority: High
Time to 1st Pt	Plane speed	Total Flight Time	Mission Time
3A = 028 minutes	375 knots	270 minutes	3A = 282 minutes

This flight is based on the P3 NW passage flight but has been shortened slightly for the Falcon jet. Minutes per segment are displayed.

Figure 3A.



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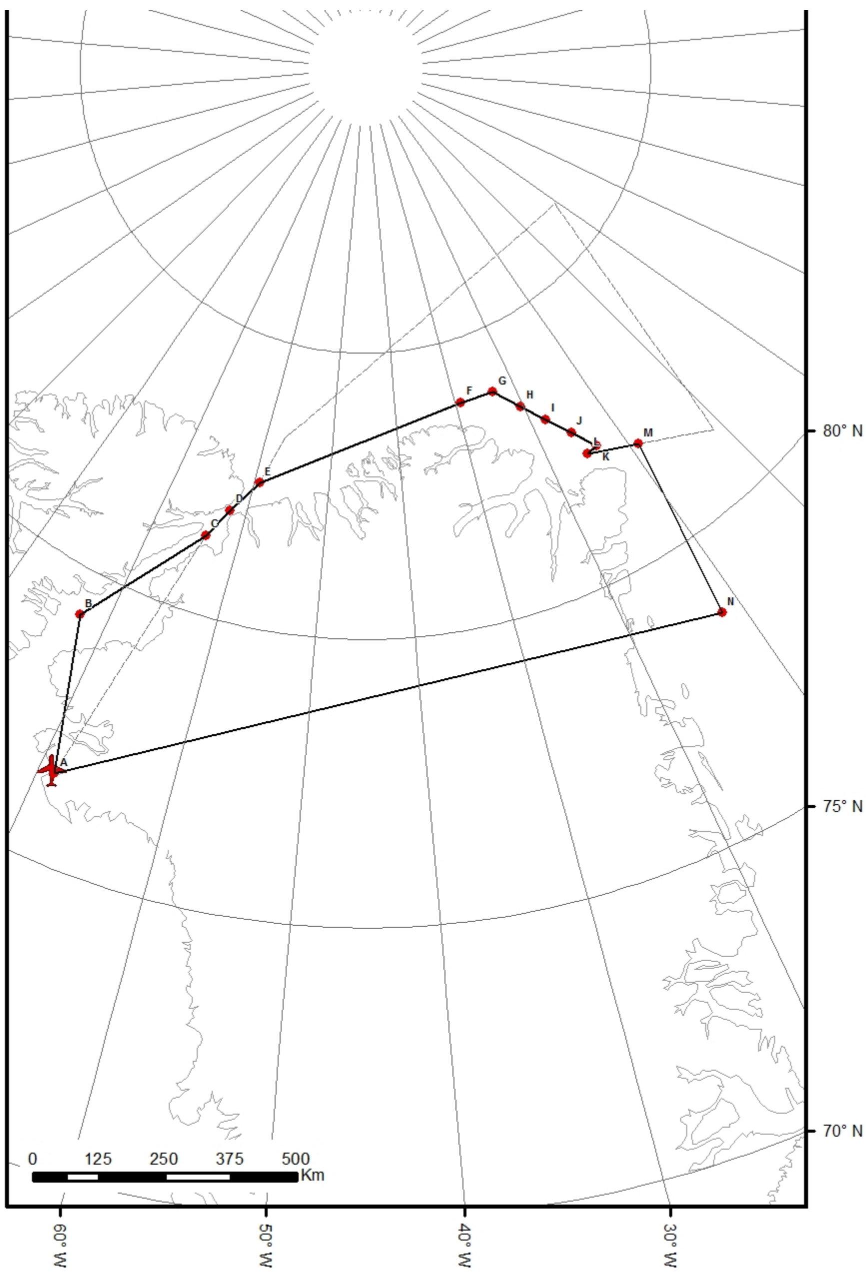
Fram Gateway			Priority: Medium*
Time to 1st Pt	**Plane speed**	**Total Flight Time**	**Mission Time**
5B = 034 minutes	375 knots	270 minutes	5B = 275 minutes

This flight repeats a portion of the 2012 P-3 April 2nd Fram Gateway flight and the 2012 April 8th Mabel flight (between waypts E and M). B to E have been moved slightly to go more up center of Nares Strait (following March 9th telecon). The P-3 flight plan is shown in dashed grey.

Notes after 3/9/2012 telecon:

- *There are potentially two ice arches here. Roughly – one between A & B, and the other near D*
- *Region M-N will be a new data region*



Cryosat Under-Flight			Priority: Medium
Time to 1st Pt	**Plane speed**	**Total Flight Time**	**Mission Time**
2A = 065 minutes 2B = 106 minutes	375 knots	270 minutes	2A = 257 minutes 2B = 269 minutes

This flight covers a Cryosat orbit out and back outside of the Wingham Box. Requirements wrt Cryosat are the same as for the Wingham Box mission. The first two options show examples using ascending or descending passes with the LVIS coverage within 2 hours of Cryosat (Figures a-b

Repeat P3 track if we can, otherwise get as much coverage as possible.

Figure 2A. 8 am Start Cryosat Underflight (descending pass)

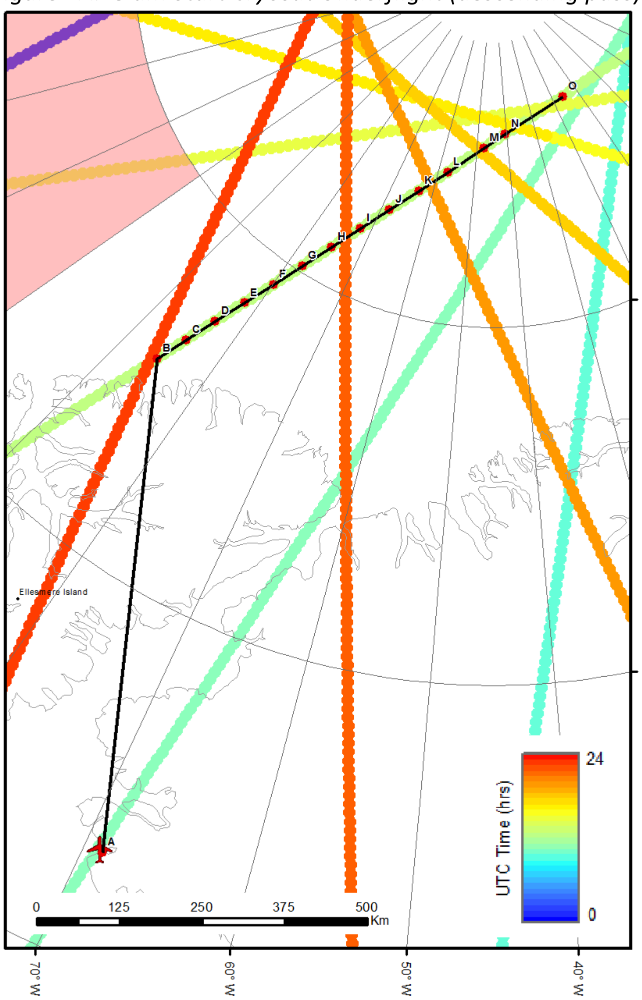
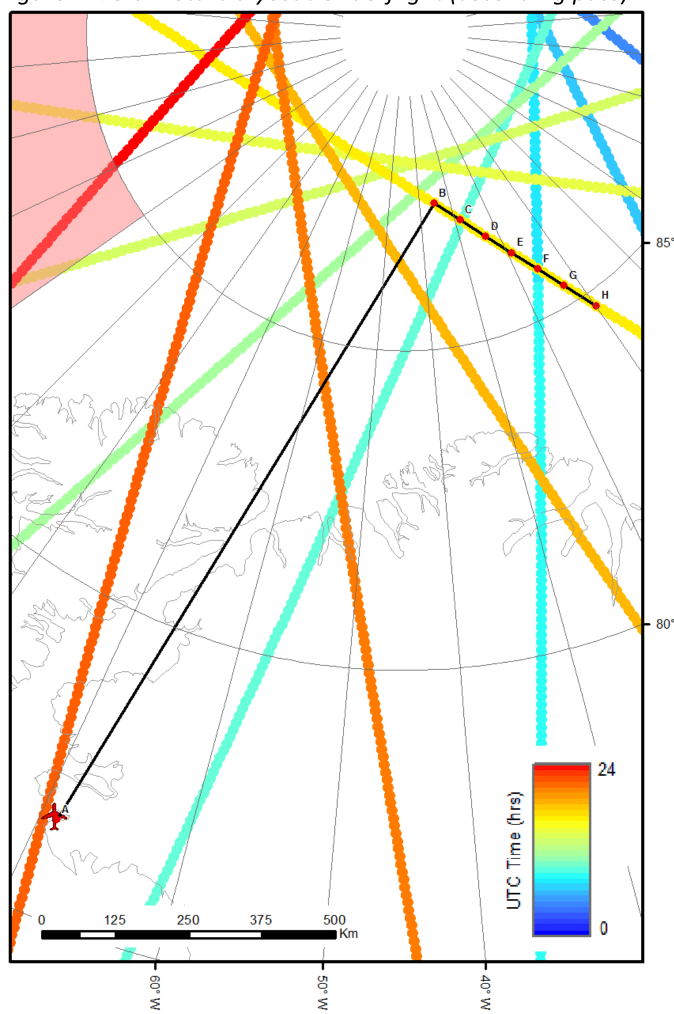


Figure 2B. 9 am Start Cryosat Underflight (ascending pass)



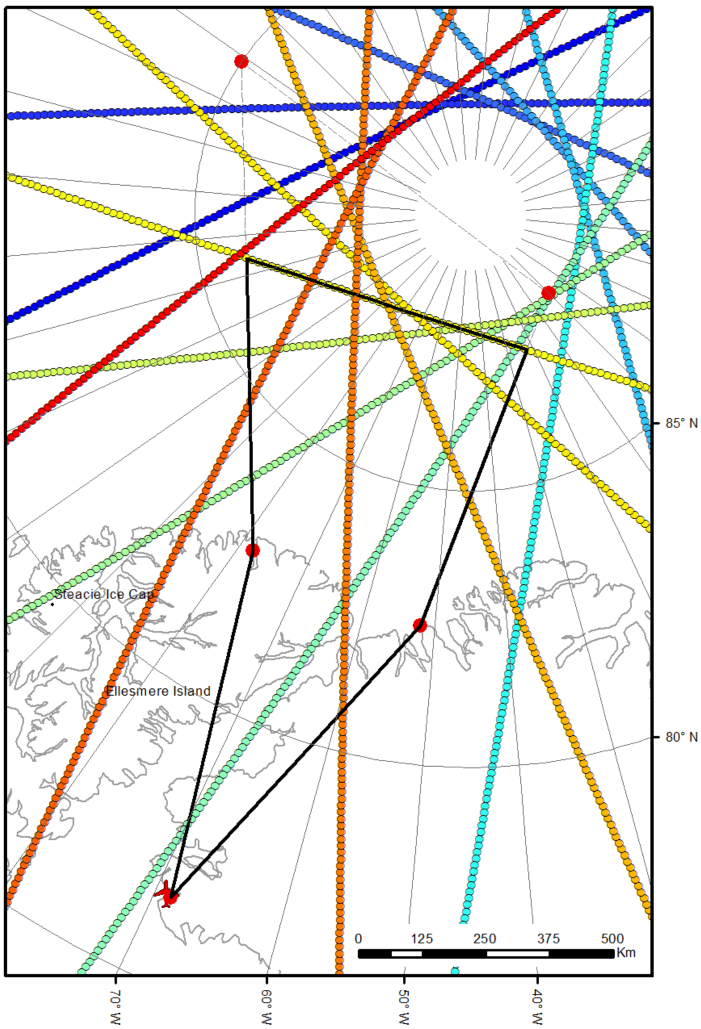
Notes after 3/9/2012 telecon

- Figure 2A is preferred overall.
- If P3 flies a Cryosat underflight, then the priority should be lowered.
- Within 50-100km of coast, Cryosat will be in SARin mode, so we may get both modes on this flight.
- A-O, and back to F will be within the 2hr window with Cryosat
- There could be a potential to fly the same Cryosat track 30 days apart.
-

North Pole Transect				Priority: Medium
Time to 1st Pt	Plane speed	Total Flight Time	Mission Time	
4B = 060 minutes	375 knots	270 minutes	4B = 273 minutes	

This flight option would repeat portions of 2012 P-3 "sinptransect". The P3 flight (dashed grey line) has been truncated to shorten the flight for the Falcon by using a Cryosat track to cross between the two P3 legs. The proposed flight lines are highlighted in black.

Figure 4B. North Pole Transect



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Historic Northwest Passage			Priority: Low
Time to 1st Pt	Plane speed	Total Flight Time	Mission Time
	400knots		4.5 hours

Thick red line = 4.5 hour flight
Dashed red line = extra (but total is 6.3hours)
Black dashed line = Northwest passage flight (plan #2)